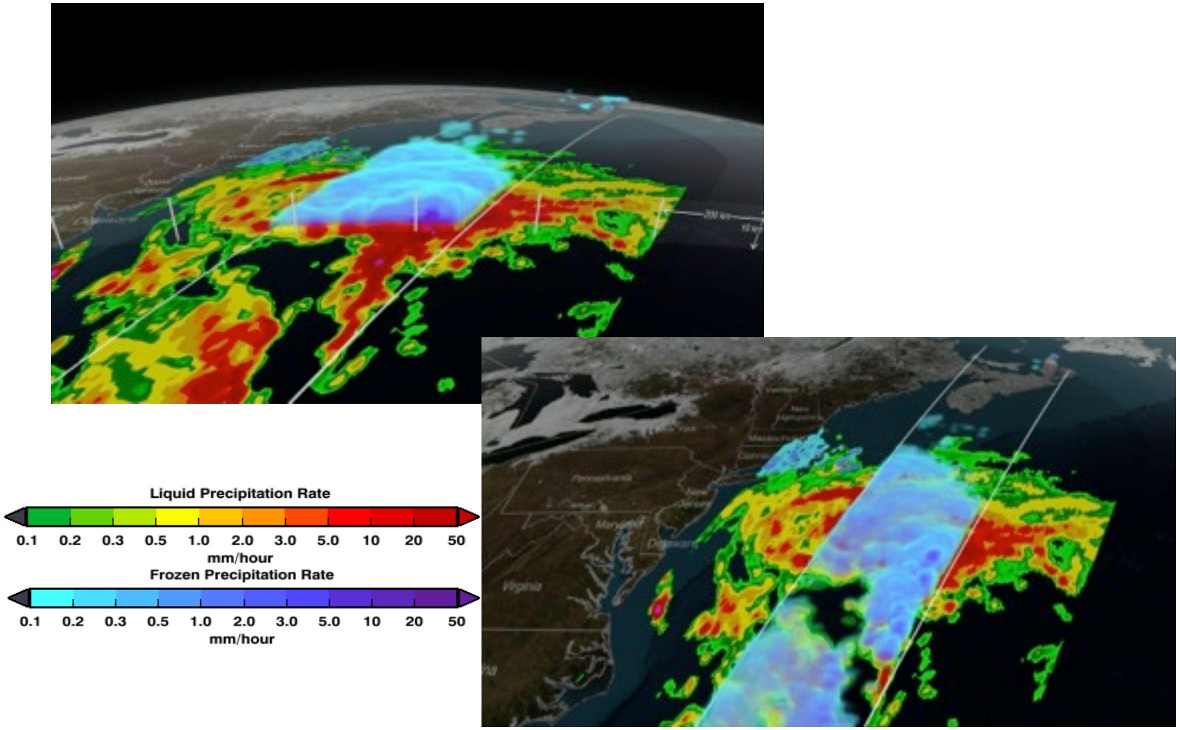
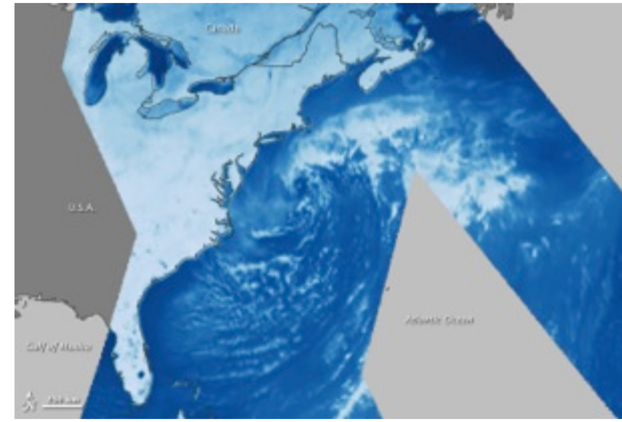
Global Precipitation Measurement (GPM) Mission Sees 2015 Nor’easter

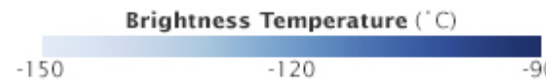
Dalia Kirschbaum, Hydrological Sciences Laboratory, Code 617, NASA GSFC



Credits: Alex Kekesi, Earth Observatory, Ellen Gray



GPM Microwave Imager (GMI) and AMSR2 radiometers observe the storm on January 27th



On Jan. 26, 2015, the GPM Core Observatory flew over a nor'easter dumping record snow on New England. These satellite image show precipitation rate of rainfall, in green to red, and snowfall, in blue to purple. The center of the storm, shown in 3-D, was offshore with far reaching bands of snowfall.

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Abstract: At 5:05 p.m. EST Monday, Jan. 26, 2015, the Global Precipitation Measurement mission's Core Observatory flew over the nor'easter dumping snow on New England. This satellite image shows precipitation rate of rainfall, in green to red, and snowfall, in blue to purple. The center of the storm, shown in 3-D, was offshore with far reaching bands of snowfall. More intense snow rates are shown in shades of blue, which can be seen on the northern edge of the storm and also over land up the coast from New York to Maine and into Canada, as well in the upper atmosphere before turning to heavy rainfall over the ocean.

References:
http://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4266

Data Sources: Global Precipitation Measurement Microwave Imager (GMI) and Dual-frequency Radar (DPR)

Technical Description of Figures:

Figure 1 (top right) Overhead view of the GMI and DPR instruments showing the two swath extents (DPR: KaPR = 120 km, KuPR = 245 km; GMI: 885 km). Blue denotes snow and red to green colors show rain.

Figure 2 (bottom left) Same view of the storm but looking at a cross section through the DPR.

Figure 3 (bottom right) GMI and AMSR2 radiometer measurements observed for the same storm on January 27th, 2015. Blue indicates bright temperature (in degree C)

Scientific significance:
The GPM Core Observatory is the first satellite specifically designed to measure falling snow. The DPR can also provide important clues into how snow, ice and rain are distributed in a storm. In this example, we are able to observe this significant East Coast Nor'easter as it is intensifying over the ocean. The DPR also demonstrates the capability to observe the melting layer (difference between solid and liquid precipitation) within the storm.

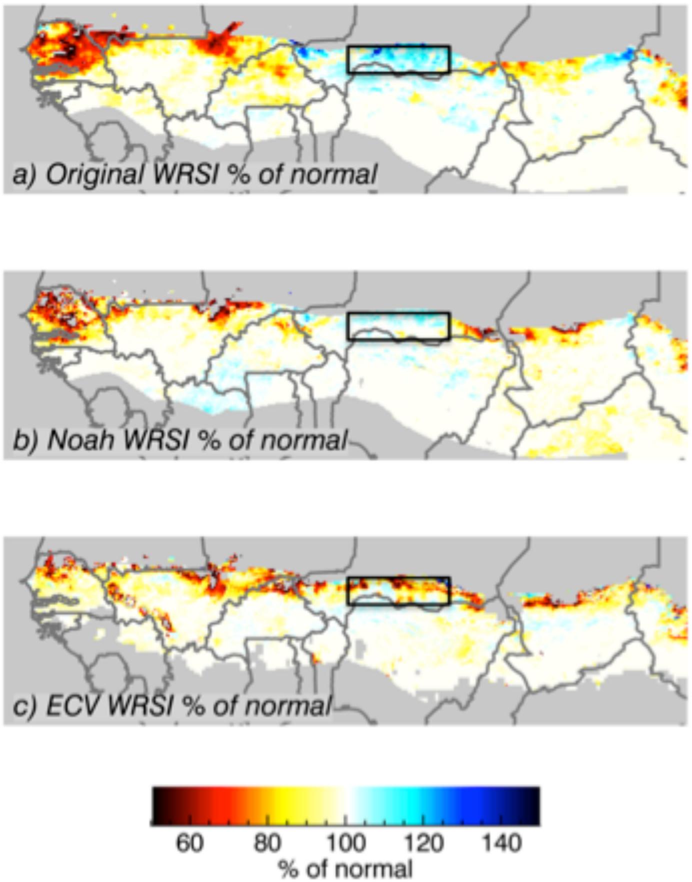
Relevance for future science and relationship to Decadal Survey:
The Global Precipitation Measurement (GPM) mission is an international network of satellites that provide the next-generation global observations of rain and snow. Building upon the success of the Tropical Rainfall Measuring Mission (TRMM), the GPM concept centers on the deployment of a "Core" satellite carrying an advanced radar / radiometer system to measure precipitation from space and serve as a reference standard to unify precipitation measurements from a constellation of research and operational satellites.

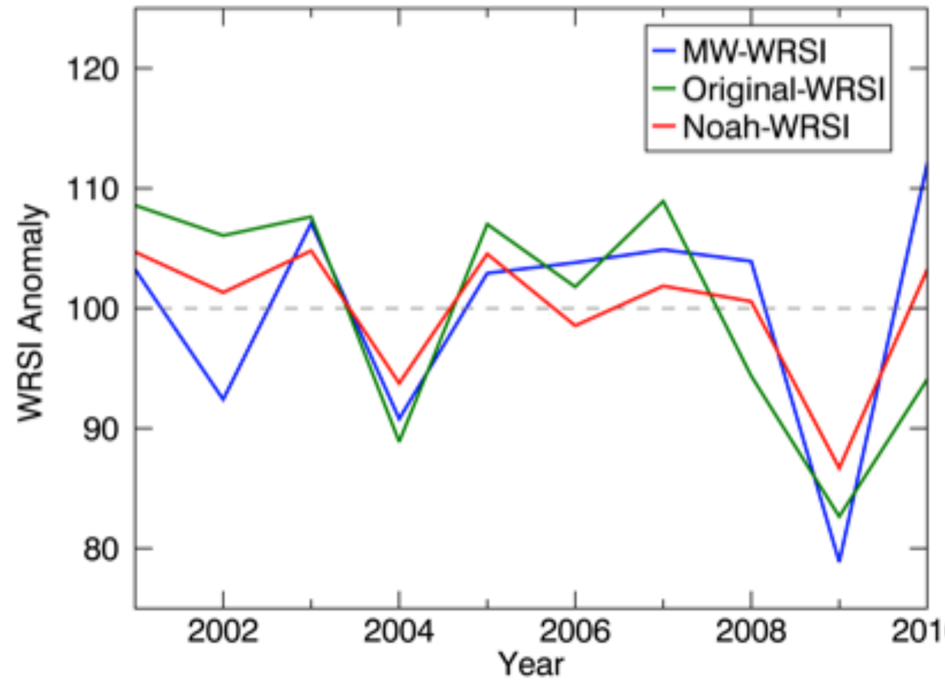
Credits:
Alex Kekesi (GST), Lead Animator, **Greg Shirah** (NASA/GSFC), Animator, **Ryan Fitzgibbons** (USRA), Lead Producer
Rani Gran (NASA/GSFC), Producer, **Gail Skofronick Jackson** (NASA/GSFC), Lead Scientist, **Dalia B Kirschbaum** (NASA/GSFC), Lead Scientist
George Huffman (NASA/GSFC), Lead Scientist, **Laurence Schuler** (ADNET Systems, Inc.), Lead Project Support
Ian Jones (ADNET Systems, Inc.), Project Support, **Ellen T. Gray** (ADNET Systems, Inc.), Lead Writer

Calculating crop water requirement satisfaction in the West Africa Sahel with remotely sensed soil moisture

Amy McNally, Kristi Arsenault, Christa Peters-Lidard, Hydrological Sciences Laboratory, Code 617, NASA/GSFC

2002





To facilitate application by partners at USGS and USAID, we used simulated-SMAP and NASA Land Information System (LIS) soil moisture to compute the Water Requirement Satisfaction Index (WRSI). Rainfall and microwave derived WRSI anomalies tend to agree, but may differ in sign when conditions are closer to average, as seen in Niger 2002.

Figures from *McNally et al. 2015*

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Abstract: The Office of Food for Peace (FFP) of the U.S Agency for International Development (USAID) manages emergency response food aid programs for the U.S. Government. These programs target the vulnerable populations of the poorest countries in the world. The Famine Early Warning Systems Network (FEWS NET) is FFP's food aid decision support system that identifies vulnerable communities in need of food aid. The FLDAS project has implemented a version of the FEWS NET's operational Water Requirement Satisfaction Index (WRSI) model, the CPC-RFE2 Africa rainfall product. It is also being developed to incorporate microwave and modeled soil moisture (McNally et al. 2015) and to expand agricultural drought and water resources monitoring and forecasting to include Yemen.

The Soil Moisture Active Passive (SMAP) mission will provide soil moisture data with unprecedented accuracy, resolution, and coverage, enabling models to better track agricultural drought and estimate yields. In turn, this information can be used to shape food-and-water-related policy from commodity markets to humanitarian relief efforts. New data alone, however, do not translate to improvements in drought and yield forecasts. New tools will be needed to transform SMAP data into agriculturally meaningful products. The objective of this study was to evaluate the possibility and efficiency of replacing the rainfall-derived soil moisture component of a crop water stress index with SMAP data. To demonstrate the approach we use microwave soil moisture from the European Space Agency and simulated soil moisture from the FLDAS. Over a West Africa domain, we found the new approach to be a feasible and useful way to quantitatively assess how satellite-derived rainfall and soil moisture track agricultural water deficits.

References:
McNally, A., G.J. Huask, M. Brown, M. Carroll, C. Funk, S. Yatheendradas, K. Arsenault, C. Peters-Lidard, and J.P. Verdin. Calculating Crop Water Requirement Satisfaction in the West Africa Sahel with Remotely Sensed Soil Moisture. *Journal of Hydrometeorology*, doi:10.1175/JHM-D-14-0049.1 (2015).

Data Sources: Rainfall data from NOAA/CPC RFE2 (0.1 degree, 2000-present). Metrological inputs for LIS-Noah is from NCEP GDAS, and geoWRSI used USGS EROS Reference ET, also derived from GDAS. Microwave soil moisture is from the ESA Essential Climate Variable merged active-passive product http://www.esa-soilmoisture-cci.org/

Technical Description of Images:
Figure 1: Map of WRSI anomalies from different SM products in 2002. In Niger there are strong differences between the rainfall- derived WRSI (bucket and Noah) and the ECV microwave WRSI. The boxed region is shown as time series in Fig. 2.

Figure 2: Average WRSI anomaly values from three different moisture inputs. Agreement is strongest in 2004 and 2009. The divergence between products in 2002 is mapped in Fig. 1.

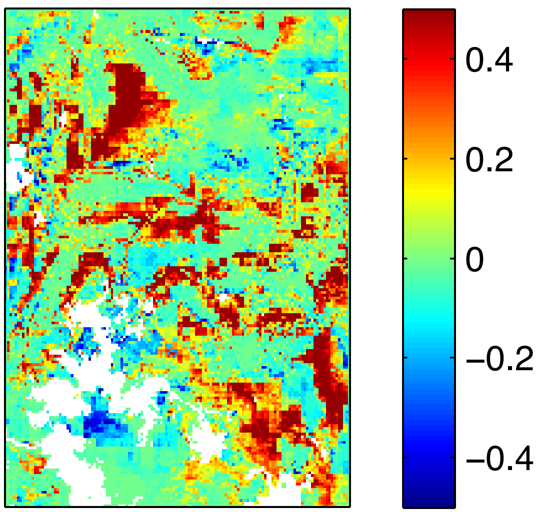
Scientific significance: The new FEWS NET Land Data Assimilation System (FLDAS) is being developed and implemented to achieve more effective use of limited available hydroclimatic observations. The high performance and flexible design of the LIS provides an infrastructure for data integration and running ensemble of land surface models over user-specified regional/global domains. These features are particularly important when characterizing, monitoring and forecasting water resources and drought in data sparse regions. Multiple models are forcings are important for qualitative convergence of evidence and quantitative characterizing uncertainty in model forcing, model physics and parameters.

Relevance for future science and relationship to Decadal Survey: Characterizing, monitoring and projecting regional rater availability for famine early warning is very relevant to NASA mission to study planet Earth from space to advance scientific understanding and meet societal needs. Partnership with USGS and USAID expands and accelerates the realization of societal benefits from Earth system Science. In addition, this work contributes to improved predictive capability for extreme weather events (drought), quantifying terrestrial productivity and quantifying key fluxes in the global water cycle.

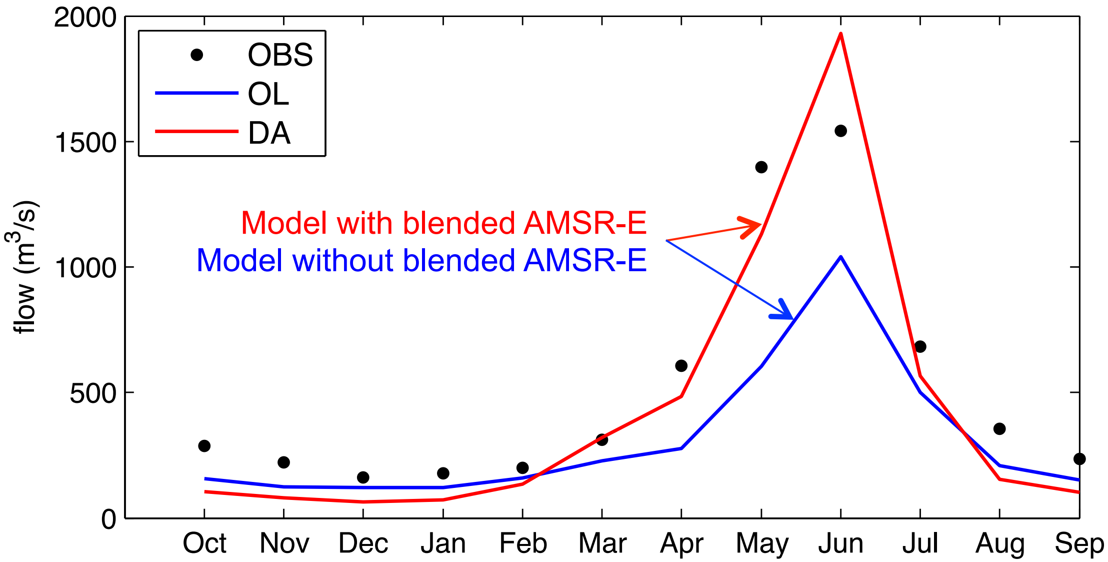
Blending Satellite Snow Depth Products with In-situ Data for Snow and Streamflow Predictions

Yuqiong Liu, Christa Peters-Lidard, Sujay Kumar, Kristi Arsenault, and David Mocko
Hydrological Sciences Laboratory, Code 617, NASA/GSFC; University of Maryland, College Park; Science Applications International Corporation

Improvement in Snow Cover Probability of Detection (POD) When Assimilating Blended AMSR-E



Improvement in Streamflow When Assimilating Blended AMSR-E (Upper Colorado River at Lees Ferry)



Assimilating AMSR-E snow depth data blended with in-situ snow observations while incorporating terrain aspect and MODIS snow cover leads to considerably improved snow and streamflow predictions in the Upper Colorado River Basin.

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Abstract: We enhance the previous optimal interpolation algorithm (Liu et al., 2013) for blending satellite-based snow depth data with in situ observations by incorporating terrain aspect and MODIS snow cover. The enhanced algorithm is applied to blending AMSR-E snow depth data with snow observations from the Snow Telemetry (SNOTEL) network and the Global Historical Climatology Network (GHCN). Assimilating the blended snow depth products into the Noah land surface model leads to significant improvements in snow and streamflow predictions in the Upper Colorado River Basin.

References:

Liu, Y., C. Peters-Lidard, S. Kumar, K. Arsenualt, and D. Mocko, 2015. Blending satellite-based snow depth products with in situ observation for streamflow predictions in the Upper Colorado River Basin. *Water Resources Research*. In press.
Liu, Y., C. D. Peters-Lidard, S. Kumar, J. L. Foster, M. Shaw, Y. Tian, and G. M. Fall, 2013. Assimilating satellite-based snow depth and snow cover products for improving snow predictions in Alaska, *Adv. Water Resour.*, *54*, 208–227.

Data Sources: Datasets used in this study include the NLDAS-2 forcing dataset, SNOTEL snow water equivalent data, GHCN snow depth data, AMSR-E snow depth data, MODIS snow cover data (MOD10C1), CMC snow depth data, and natural streamflow data from the US Bureau of Reclamation.

Technical Description of Figures:

Figure 1 (left) Assimilating the blended AMSR-E snow depth products into the Noah land surface model leads to considerable improvements in snow cover probability of detection (POD) over the model-only prediction (i.e., without assimilating the blended AMSR-E). Note the snow cover POD is calculated using the MODIS snow cover product (MOD10C1) as a reference.

Figure 2 (right) The mean monthly streamflow simulated by the Noah model with (red) and without (blue) assimilating the blended AMSR-E snow depth products, as compared to the natural flow data (black), showing significant improvement from assimilating the blended AMSR-E snow depth products in streamflow prediction in the Upper Colorado River Basin.

Scientific significance:

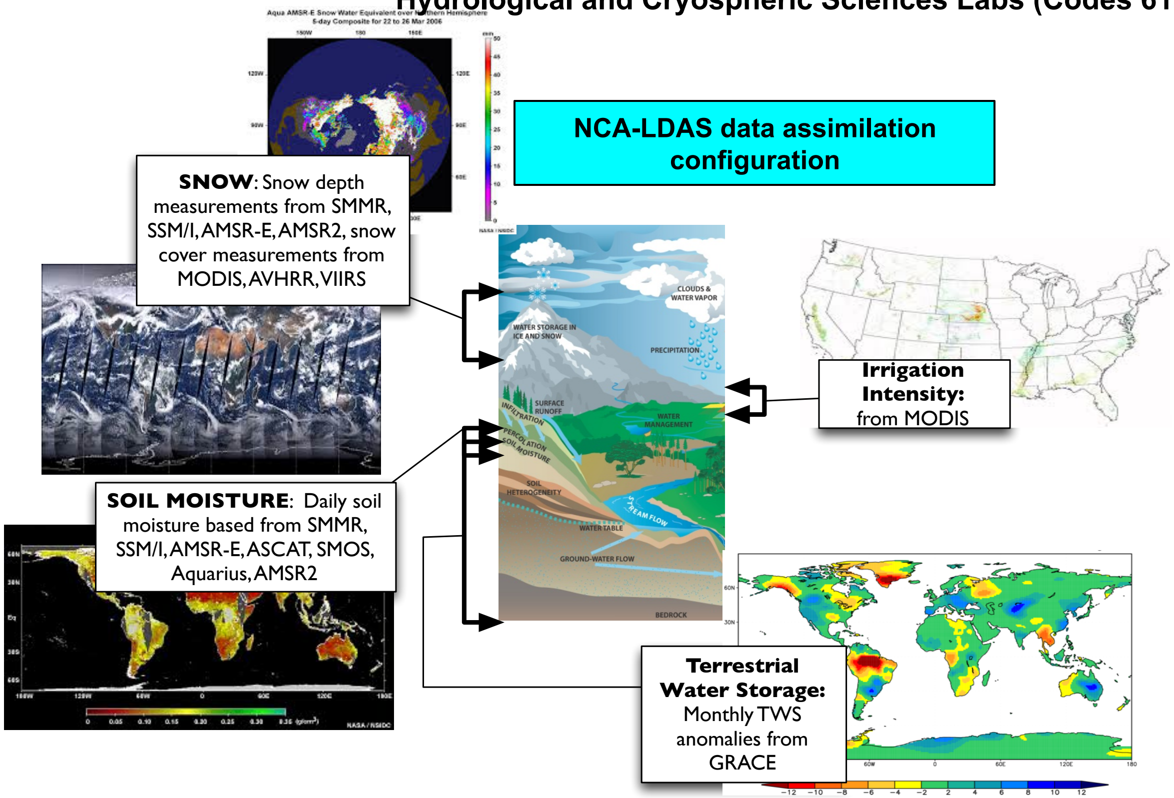
We develop an efficient algorithm to blend satellite-based snow depth and water equivalent data with in-situ snow observations, which can significantly reduce bias in the raw satellite snow depth and water equivalent products so that they can be more effectively used for various applications such as numerical weather prediction, hydrologic forecasting, and water resources management including drought monitoring.

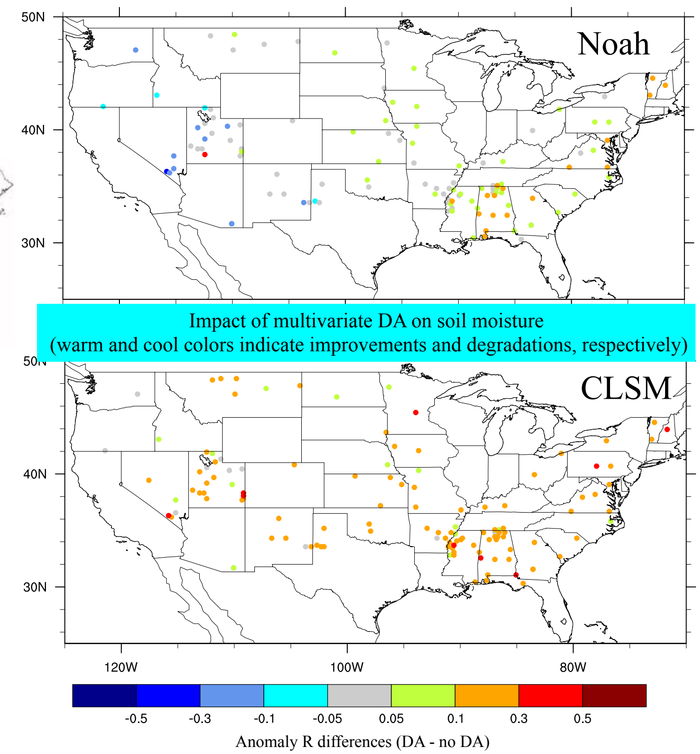
Relevance for future science and relationship to Decadal Survey:

The satellite-station snow blending algorithm developed in this study can be effectively employed for bias-correcting snow depth and water equivalent products from other existing or upcoming satellite-based passive microwave (PMW) instruments such as AMSR-2, while at the same time providing an efficient mechanism for using the snow cover information from visible sensors such MODIS and VIIRS.

Multivariate assimilation of satellite-derived remote sensing datasets in the National Climate Assessment Land Data Assimilation System (NCA-LDAS)

Sujay Kumar, Christa Peters-Lidard, Michael Jasinski, David Mocko, Rolf Reichle, Ben Zaitchik, Augusto Getirana, Yuqiong Liu, Matt Rodell, Kristi Arsenault, Bailing Li, Jordan Borak, Hiroko Kato, Dorothy Hall, James Foster, George Riggs – Hydrological and Cryospheric Sciences Labs (Codes 617, 615); GMAO, NASA/GSFC





NCA-LDAS assimilates available remote sensing measurements of soil moisture, snow, terrestrial water storage and irrigation intensity.

The results indicate that multivariate assimilation of satellite remote sensing datasets are helpful in improving water and energy budget components.

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Abstract: An integrated terrestrial water analysis system, or NCA-LDAS has been developed as an end-to-end enabling tool for the National Climate Assessment (NCA). NCA-LDAS is built upon NASA's Land Information System (LIS) and its associated software framework for input data processing (Land surface Data Toolkit or LDT) and model evaluation (Land surface Verification Toolkit or LVT). NCA-LDAS employs two surface hydrology models, NCEP's Noah and NASA's GMAO Catchment model (CLSM), both forced with a 34 year (1979-2013+) record or in situ observations and satellite reanalysis products over the U.S. This work examines the impact of assimilating satellite remote sensing datasets (soil moisture from SMMR, SSM/I, ASCAT, AMSR-E; snow depth from SMMR, SSM/I, AMSR-E; snow cover from IMS and MODIS; terrestrial water storage from GRACE; irrigation intensity from MODIS) in NCA-LDAS.

References:

Kumar, S.V., C.D. Peters-Lidard, D. Mocko, R. Reichle, Y. Liu, K. Arsenault, Y. Xia, M. Ek, G. Riggs, B. Livneh, M. Cosh: 2014 Assimilation of remotely sensed soil moisture and snow depth retrievals for drought estimation. *Journal of Hydrometeorology*, 15, 2446-2469, doi: http://dx.doi.org/10.1175/JHM-D-13-0132.1

Data Sources: Passive soil moisture and snow depth retrievals from SMMR, SSM/I and AMSR-E, soil moisture retrievals from ASCAT, snow cover measurements from IMS and MODIS, terrestrial water storage data from GRACE, irrigation intensity estimates from MODIS.

Technical Description of Figures:

Figure 1 Schematic of the concurrent data assimilation scenario for NCA-LDAS where relevant water budget components are constrained by satellite remote sensing datasets.

Figure 2 Shows the differences in anomaly R from data assimilation in soil moisture fields (anomaly R (DA) – anomaly R (no DA)) from multivariate assimilation in Noah (top panel) and CLSM (bottom panel), compared to the soil climate analysis network (SCAN) and USDA cal/val soil moisture sites. Warm colors indicate locations of improvement and cool colors denote areas of degradation.

Scientific significance:

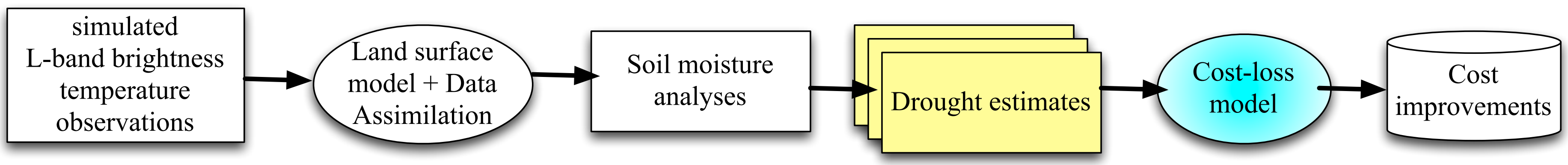
The results indicate that multivariate assimilation of satellite remote sensing datasets are helpful towards further improving NCA-LDAS model estimates. The results also demonstrate current deficiencies and challenges in extracting the relevant information content from remote sensing observations. A comprehensive evaluation of the water budget components remains a challenge due to the lack of reliable, independent and geographically co-located measurements of relevant terms.

Relevance for future science and relationship to Decadal Survey:

The ongoing work targets the use of new satellite remote sensing measurements for data assimilation within the NCA-LDAS system. The soil moisture retrievals from the Soil Moisture Active Passive (SMAP) mission will be incorporated into the suite of remote sensing products employed in the NCA-LDAS system and the impact of SMAP for providing land surface model improvements will be evaluated.

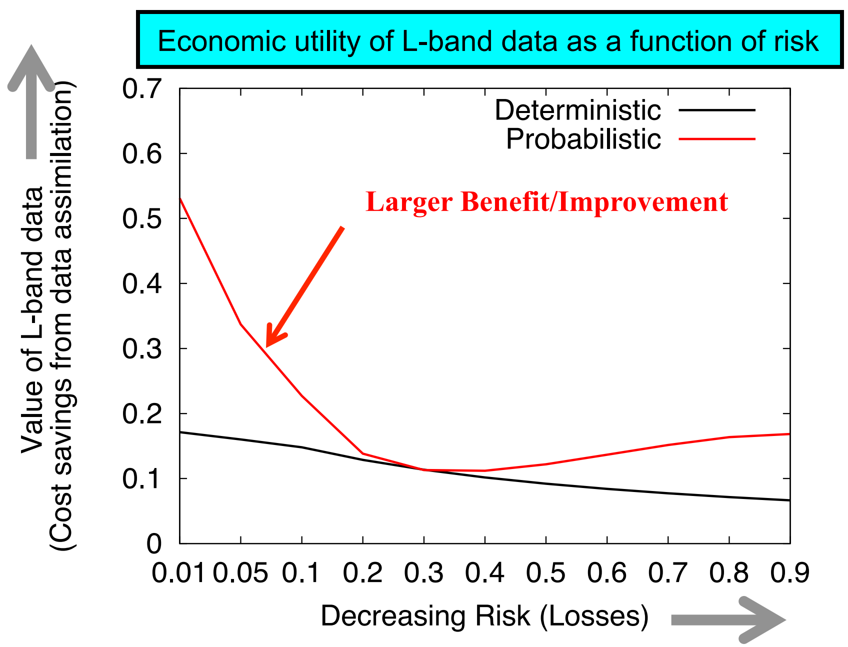
Assessing the impact of L-band observations on drought estimation: A decision theoretic approach in an OSSE environment

Sujay Kumar, Christa Peters-Lidard, Ken Harrison, Joseph Santanello, Dalia Kirschbaum– Hydrological Sciences Laboratory, Code 617, NASA/GSFC



This study demonstrates a soil moisture Observing System Simulation Experiment (OSSE) that employs simulated L-band measurements towards improving drought estimates. A decision-theory based analysis is conducted to assess the economic utility of the observations and to demonstrate the use of probabilistic information from the model towards improving drought representations.

The results of the study indicates that L-band soil moisture measurements are helpful not only in improving soil moisture states, but also for providing economic utility to end-use applications such as droughts.



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Abstract: Observing System Simulation Experiments (OSSEs) are often conducted to evaluate the worth of existing data and data yet to be collected from proposed new missions. As missions increasingly require a broader ``Earth systems'' focus, it is important that the OSSEs capture the potential benefits of the observations on end-use applications. Towards this end, the results from the OSSEs must also be evaluated with a suite of metrics that capture the value, uncertainty, and information content of the observations while factoring in both science and societal impacts. This study demonstrates a soil moisture OSSE that employs simulated L-band measurements towards improving drought estimates, using the NASA Land Information System (LIS). A decision-theory based analysis is conducted to assess the economic utility of the observations towards improving these applications.

References:

Kumar, S.V., K.W. Harrison, C.D. Peters-Lidard, J.A. Santanello, D. Kirschbaum: 2014 Assessing the impact of L-band observations on drought and flood risk estimation: A decision theoretic approach in an OSSE environment. *Journal of Hydrometeorology*, 15, 2140-2156, doi: http://dx.doi.org/10.1175/JHM-D-13-0204.1

Data Sources: Simulated L-band (1.4Ghz) brightness temperature observations for horizontal and vertical polarizations at ~36 km spatial resolution.

Technical Description of Figures:

Figure 1 Schematic of an end-to-end OSSE that employs simulated L-band measurements for data assimilation with a land surface model to improve soil moisture states. Estimates of drought are generated from the soil moisture states. A cost-loss model is then used to compute the economic utility of the observations for improving drought estimates.

Figure 2 Figure 2: Value of Information (VOI), a normalized measure of the cost savings from data assimilation, as a function of different cost/loss ratios from the deterministic and probabilistic estimates for D2 drought category. For low cost/loss ratios, the use of probabilistic drought forecasts provides greater value from DA compared to the deterministic drought forecasts. The probabilistic estimate is from an ensemble of model simulations and the deterministic estimate is from the ensemble mean.

Scientific significance:
The results suggest that the improvements in surface and root zone soil moisture fields obtained through the assimilation of L-band measurements are effective in providing improvements in the drought and flood risk assessments as well. The decision theory analysis not only demonstrates the economic utility of observations, but also shows that the use of probabilistic information from the model simulations is more beneficial compared to the use of corresponding deterministic estimates. The experiment also demonstrates the value of a comprehensive modeling environment such as LIS for conducting end-to-end OSSEs by linking satellite observations, physical models, data assimilation algorithms and end-use application models in a single integrated framework.

Relevance for future science and relationship to Decadal Survey:
This study demonstrates that the L-band observations from the Soil Moisture Active Passive (SMAP) mission are likely to help towards improving representation of applications such as droughts.

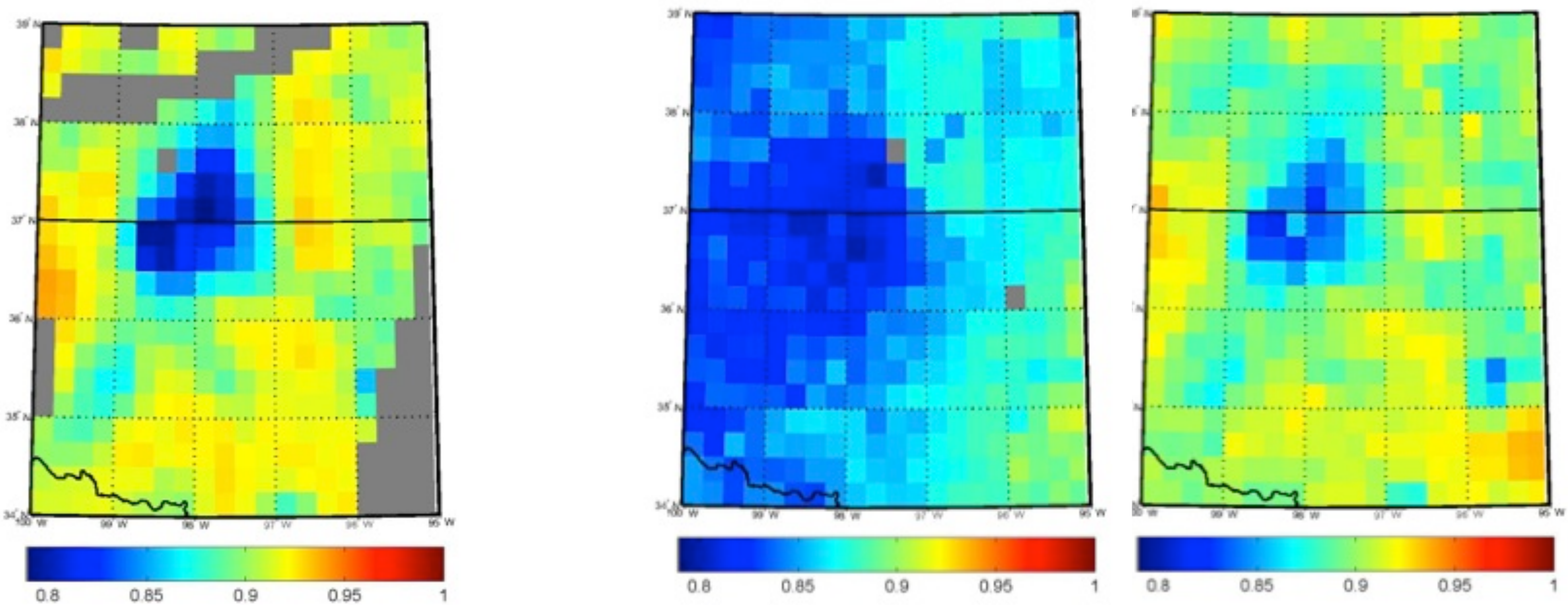
Calibration to improve simulation of microwave emissivity over the U.S. Southern Great Plains (SGP) for GPM

Christa Peters-Lidard, Ken Harrison, Yudong Tian, and Sujay Kumar, Hydrological Sciences Laboratory, Code 617, NASA GSFC; Univ. of Maryland; Science Applications International Corporation

<u>Emissivity (which multiplied by surface temperature = the background land signal for GPM rainfall retrievals), one day after historic SGP storms in 2008…</u>

as *modeled*…

as *observed* | ***before*** calibration | ***after*** calibration



Drawing on the new, more comprehensive calibration capability in the NASA Land Information System (LIS), <u>we can now achieve up to 20% average reduction in emissivity error as compared to GPM approaches in operations that rely on historical time (e.g., monthly) averages (Harrison et al., 2014).</u>

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Abstract: Better estimation of land surface microwave emissivity promises to improve over-land precipitation retrievals in the GPM era. Forward models of land microwave emissivity are available but have suffered from poor parameter specification and limited testing. Forward models were calibrated and the accompanying change in predictive power was evaluated. With inputs (e.g., soil moisture) from the Noah land surface model and applying MODIS LAI data, two microwave emissivity models were tested, the Community Radiative Transfer Model (CRTM) and Community Microwave Emission Model (CMEM). The calibration was conducted with the NASA Land Information System (LIS) parameter estimation subsystem using AMSR-E based emissivity retrievals for the calibration dataset. The extent of agreement between the modeled and retrieved estimates was evaluated using the AMSR-E retrievals for a separate 7-year validation period. Results indicate that calibration can significantly improve the simulation of emissivity, simulating emissivity with an across-channel average RMSE of about 0.013, or about 20% lower than if relying daily estimates based on climatology. The results also indicate that calibration of the microwave emissivity model alone, as was done in prior studies, results in as much as 12% higher across-channel average RMSE. To extract the maximum reduction in RMSE, it is necessary to jointly calibrate the land surface and microwave emissivity models.

References: Harrison, K.W., Tian, Y., Peters-Lidard, C.D., Ringerud, S., and Kumar, S.V. Calibration to improve forward model simulation of microwave emissivity at GPM frequencies over the U.S. Southern Great Plains, IEEE Transactions on Geoscience and Remote Sensing. (in review process, Dec. 2014)

Data Sources: Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E). Aqua-MODerate resolution Imaging Spectroradiometer (MODIS) cloud masks and Collection 5 (MCD15A2.005) Leaf Area Index (LAI). North American Land Data Assimilation System (NLDAS) forcings, European Centre for Medium-Range Weather Forecasts (ECMWF) interim reanalysis (ERA-Interim) 3-hourly, 1-degree surface skin temperature and water vapor.

Technical Description of Figures:

Emissivity is a unitless measure referring to the efficiency with which an object, here the land surface, radiates energy as compared to a perfect ("blackbody") radiator. The importance of emissivity is that it and temperature dictate brightness as measured by a microwave radiometer. Wet soils are of lower microwave emissivity than dry soils, and (at the same temperature) therefore appear dimmer to the radiometer, though this signal is tempered by vegetative cover.

Figure 1 (left) 10.65 GHz horizontally polarized (H-pol) emissivity *observations* over the Southern Great Plains (SGP) on September 16, 2008 descending pass as estimated from AMSR-E brightness temperatures (with atmospheric corrections and application of reanalysis temperature datasets). In the days leading up to the time of this image, up to 12 inches fell over the SGP from Sept. 11-15, 2008, a result of a stationary boundary interacting with the tropical remnants of Lowell. The rains resulted in very high soil moisture and hence, in areas without heavy vegetative cover, low values of emissivity (as indicated by the darker blues).

Figure 2 (middle) Same as Figure 1 but as estimated based on forward modeling. The forward model consists of the coupling of the Noah land surface model and CMEM. Results shown are after bias correction.

Figure 3 (right) Same as Figure 2 but after joint calibration of Noah and CMEM to six months of AMSR-E emissivity estimates during the warm season of 2008.

Scientific significance: Securing more accurate precipitation retrievals at higher latitudes where the land surface is more complex depends on the ability to estimate land surface microwave emissivity.

Relevance for future science and relationship to Decadal Survey: Improving the accuracy of precipitation retrievals in the GPM era is critical to a range of science and other applications.

Seasonal Parameterizations of the Tau-Omega Model for SMAP

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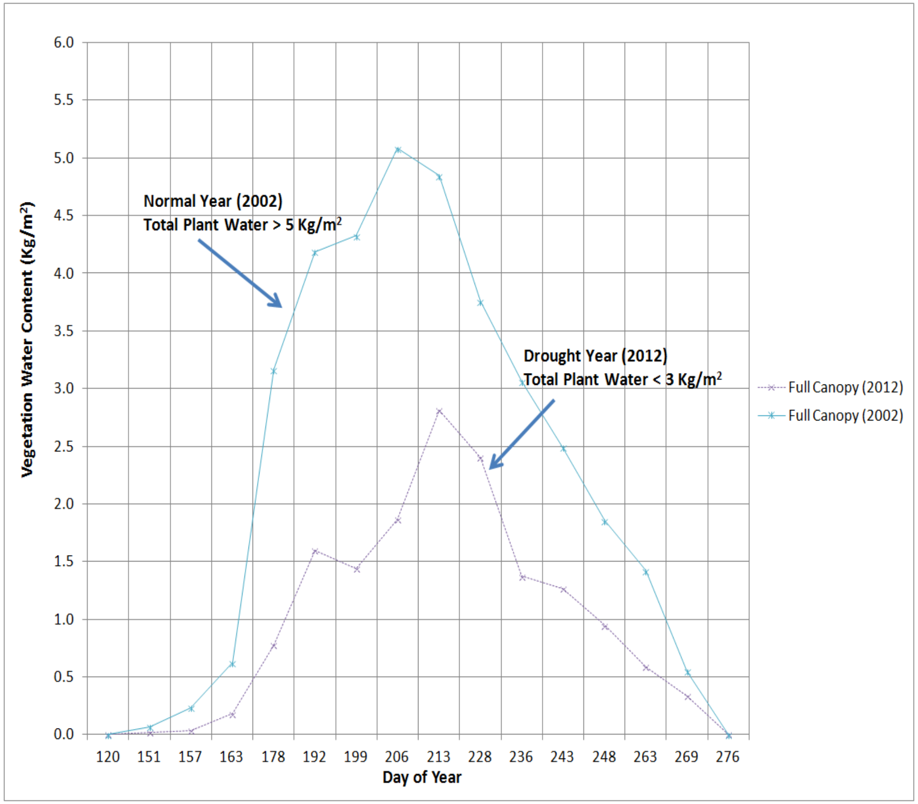
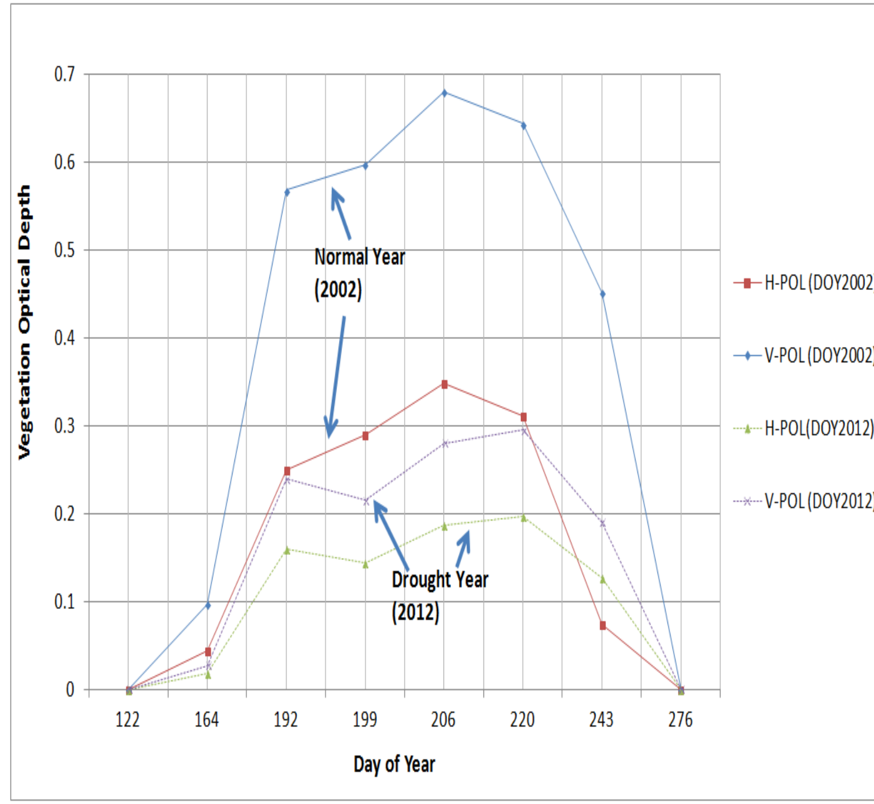
M. Cosh / USDA; R. Lang / GWU

Seasonal Variation in Corn Canopy Water (VWC)



Seasonal Variation in Corn Optical Depth (tau)



Two growing season experiments over corn 10 years apart demonstrated that:
(1) the relative distribution of VWC among corn canopy constituents remains ~ the same in drought and normal years although the absolute amount of VWC may vary; (2) ratio of *tau* and *VWC* (*b*) is ~ constant; (3) *b* and *tau* have a polarization dependence; (4) using the correct parameterization of *tau* produces accurate soil moisture retrievals in both years (RMSE ~.02-.03 m^3/m^3).

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References:

O'Neill, P., A. Joseph, P. Srivastava, M. Cosh, and R. Lang, "Seasonal Parameterizations of the Tau-Omega Model using the ComRAD Ground-Based SMAP Simulator," Proc. of IGARSS'14, IEEE, Quebec City, Canada, July 13-18, 2014, DOI: 10.1109/IGARSS.2014.6946961.

O'Neill, P., M. Kurum, A. Joseph, J. Fuchs, P. Young, M. Cosh, and R. Lang, "L-Band Active / Passive Time Series Measurements over a Growing Season using the ComRAD Ground-Based SMAP Simulator," Proc. of IGARSS'13, IEEE, Melbourne, Australia, July 22-26, 2013, DOI: 10.1109/IGARSS.2013.6721086.

O'Neill, P., S, Chan, E. Njoku, T. Jackson, and R. Bindlish, *SMAP Level 2 & 3 Soil Moisture (Passive) Algorithm Theoretical Basis Document (ATBD)*, Rev. A, JPL D-66480, Jet Propulsion Laboratory, December, 2014.

Entekhabi, D., E, Njoku, P. O'Neill, K. Kellogg, plus 19 others, "The Soil Moisture Active Passive (SMAP) Mission," Proceedings of the IEEE, Vol. 98, No. 5, May, 2010, DOI: 10.1109/JPROC.2010.2043918.

O'Neill, P., A. Joseph, G. De Lannoy, R. Lang, C. Utku, E. Kim, P. Houser, and T. Gish, "Soil Moisture Retrieval Through Changing Corn Using Active/Passive Microwave Remote Sensing," Proc. of IGARSS '03, Toulouse, France, July, 2003.

Data Sources: GSFC's truck-mounted ComRAD radar / radiometer instrument system was used as a ground-based SMAP simulator to obtain microwave data over corn coincident with measurements of soil and vegetation properties throughout the growing season in both a normal (2002) and a drought year (2012). The USDA OPE3 test site in Beltsville, MD was used for both experiments and had identical soil roughness, soil texture, and soil bulk density in both years, allowing the impacts of differences in the vegetation canopy on vegetation parameterizations of the tau-omega soil moisture retrieval model in a drought and a normal year to be examined. This project was a collaboration between GSFC, George Washington University, and USDA.

Technical Description of Figures:
SMAP passive microwave-only soil moisture retrieval algorithms are based on the zero-order tau-omega model, which requires parameterization of the vegetation effects on the observed microwave brightness temperatures (tau is the vegetation optical depth and omega the single scattering albedo). Two growing season experiments over corn 10 years apart used radar and dielectric measurements with a microwave vegetation scattering model to estimate microwave attenuation in the vegetation canopy, which was then converted into estimates of tau throughout the growing season. For each day that a passive microwave measurement was available, a tau value was interpolated from the tau growing season curves shown to the right of the figure; this tau value was then used to retrieve soil moisture for that day which was compared to the measured soil moisture. The experiments demonstrated that (1) the relative distribution of VWC (vegetation water content) among corn canopy constituents remains ~ the same in drought and normal years although the absolute amount of VWC may vary; (2) *b* values remain ~ constant, while variations in *tau* are due to variations in VWC [a commonly used parameterization for tau is *tau = b * VWC*] ; (3) *b* and *tau* have a polarization dependence; (4) using the correct parameterization of *tau* produces accurate soil moisture retrievals in both years (RMSE ~.02-.03 m^3/m^3).

Scientific significance, societal relevance, and relationships to future missions: Soil moisture plays a critical role in linking together the Earth's water, energy, and carbon cycles, and is important to a large number of applications with societal benefit. Accurate soil moisture retrieval from missions like SMAP require proper parameterization of vegetation effects in the tau-omega model. This project demonstrated that *tau* varies through the growing season for cropped soils and has a polarization dependence which should be accounted for; it also demonstrated that correct parameterization of *tau* in drought and normal years results in accurate soil moisture retrievals.